CLAIMS

1. A linear electrical machine comprising:

a coil adapted to carry electrical current;

a core disposed at least partially around the coil that provides a relatively low reluctance path for a magnetic flux, the core having a central opening; and

a movable element having a longitudinal axis adapted to linearly reciprocate in the central opening along the longitudinal axis, the movable element having only first, second and third magnets arranged along the longitudinal axis, the first magnet being adjacent the second magnet, and the second magnet being adjacent the third magnet, each of the first, second and third magnets having a different magnetic orientation.

2. The machine of claim 1, wherein none of the first, second and third magnets have a magnetic orientation such that a north pole of the magnet is oriented radially inward.

3. The machine of claim 1, wherein each magnet is hollow and has an annular shape or a polygonal cross-sectional shape.

4. The machine of claim 1, further comprising a back iron element disposed inside the magnets.

5. The machine of claim 1, wherein the core includes two halves that are assembled together in a clam-shell type arrangement to receive coil inside.

6. The machine of claim 1, further comprising a spring magnet that urges one of the first, second and third magnets to align with a portion of the core.

7. The machine of claim 6, wherein the spring magnet urges the second magnet to align with the spring magnet.

8. The machine of claim 1, wherein the first and third magnets have a north pole parallel to the longitudinal axis, and the second annular magnet has a north pole perpendicular to the longitudinal axis.

9. The machine of claim 1, wherein the second magnet has a north pole oriented radially outward, and the first and third magnets each have a north pole oriented toward second magnet.

10. The machine of claim 1, wherein each of the first, second and third magnets have a length in a direction parallel to the longitudinal axis greater than one-half of a peak displacement of the movable element from a central position.

11. A linear electrical machine comprising:

a coil adapted to carry electrical current;

a core disposed at least partially around the coil that provides a relatively low reluctance path for a magnetic flux, the core having an annular shape with a central opening;

a movable element having a longitudinal axis adapted to linearly reciprocate in the central opening along the longitudinal axis, the movable element having three magnets arranged along the longitudinal axis and adjacent each other, the magnets each having a different magnetic orientation such that the magnetic orientations of adjacent magnets are within 90 degrees of each other; and

a soft magnetic material disposed within the magnets that provides a path for flux driven by a magnetic field generated by the magnets.

12. The machine of claim 11, wherein none of the magnets included with the movable element have a magnetic orientation such that a north pole of the magnet is oriented radially inward.

13. The machine of claim 11, wherein each magnet has an annular shape.

14. The machine of claim 11, wherein the soft magnetic material comprises a sleeve disposed inside the magnets.

15. The machine of claim 11, wherein the core includes two halves that are assembled together in a clam-shell type arrangement to receive coil inside.

16. The machine of claim 11, further comprising a spring magnet that urges one of the three magnets to align with a portion of the core.

17. The machine of claim 16, wherein the spring magnet urges one of the magnets to align with the spring magnet.

18. The machine of claim 11, wherein the three magnets include a first annular magnet adjacent a second annular magnet, and a third annular magnet adjacent the second annular magnet, the first and third annular magnets have a north pole parallel to the longitudinal axis, and the second annular magnet has a north pole perpendicular to the longitudinal axis.

19. The machine of claim 18, wherein the second annular magnet has a north pole oriented radially outward, and the first and third annular magnets each have a north pole oriented toward second annular magnet.

20. The machine of claim 11, wherein each of the three magnets have a length in a direction parallel to the longitudinal axis greater than one-half a peak displacement of the movable element from a central position.

21. A linear electrical machine comprising:

a coil adapted to carry electrical current;

a core disposed in relation to the coil to provide a path for a magnetic flux adjacent the coil; and

first, second and third magnets arranged along a longitudinal axis to interact with a magnetic flux in the core which links with the coil, the first magnet being adjacent the second magnet, and the second magnet being adjacent the third magnet, each of the first, second and third magnets having a different magnetic orientation such that one of the magnets has a north pole oriented approximately perpendicular to the longitudinal axis and the other two magnets have a north pole oriented approximately parallel to the longitudinal axis;

wherein all magnets having a magnetic orientation approximately perpendicular to the longitudinal axis are oriented so the north pole of all such magnets is either radially inward or radially outward, and at least one of the magnets and the coil is arranged to move relative to the other in a linear direction parallel to the longitudinal axis .

22. The machine of claim 21, wherein none of the magnets included with the movable element have a magnetic orientation such that a north pole of the magnet is oriented radially inward.

23. The machine of claim 21, wherein each magnet has an annular shape.

24. The machine of claim 21, wherein the magnets are annular magnets and a soft magnetic material is disposed inside or outside the magnets.

25. The machine of claim 21, wherein the core includes two halves that are assembled together in a clam-shell type arrangement to receive coil inside.

26. The machine of claim 21, further comprising a spring magnet that urges one of the three magnets to align with a portion of the core.

27. The machine of claim 26, wherein the spring magnet urges one of the magnets to align with the spring magnet.

28. The machine of claim 21, wherein the magnets include a first annular magnet adjacent a second annular magnet, and a third annular magnet adjacent the second annular magnet, the first and third annular magnets have a north pole parallel to the longitudinal axis, and the second annular magnet has a north pole perpendicular to the longitudinal axis.

29. The machine of claim 28, wherein the second annular magnet has a north pole oriented radially outward, and the first and third annular magnets each have a north pole oriented toward second annular magnet.

30. The machine of claim 21, wherein each of the magnets has a length in a direction parallel to the longitudinal axis greater than one-half a maximum amount of relative movement between the magnets and the coil along the longitudinal axis.

31. A linear electrical machine comprising:

a coil adapted to carry electrical current;

a core disposed in relation to the coil to provide a path for a magnetic flux adjacent the coil; and

first, second and third magnets arranged along a longitudinal axis to interact with a magnetic flux in the core linking with the coil, the first magnet being adjacent the second magnet, and the second magnet being adjacent the third magnet, each of the first, second and third magnets having a different magnetic orientation;

wherein at least one of the magnets and the coil is arranged to move relative to the other in a linear direction parallel to the longitudinal axis, and the first, second and third magnets each have a length in the longitudinal direction that is greater than one-half of a maximum amount of relative movement of the magnets and the coil along the longitudinal axis.

32. The machine of claim 31, wherein none of the magnets included with the movable element have a magnetic orientation such that a north pole of the magnet is oriented in a direction away from the core.

33. The machine of claim 31, wherein each magnet comprises a plurality of separate magnet segments arranged in an annular configuration.

34. The machine of claim 31, wherein the magnets are annular magnets and a soft magnetic material is disposed inside or outside the magnets.

35. The machine of claim 31, wherein the core includes two halves that are assembled together in a clam-shell type arrangement to receive coil inside.

36. The machine of claim 31, further comprising a spring magnet that urges one of the three magnets to align with a portion of the core.

37. The machine of claim 36, wherein the spring magnet urges one of the magnets to align with the spring magnet.

38. The machine of claim 31, wherein the magnets include a first annular magnet adjacent a second annular magnet, and a third annular magnet adjacent the second annular magnet, the first and third annular magnets have a north pole parallel to the longitudinal axis, and the second annular magnet has a north pole perpendicular to the longitudinal axis.

39. The machine of claim 38, wherein the second annular magnet has a north pole oriented radially outward, and the first and third annular magnets each have a north pole oriented toward second annular magnet.

40. The machine of claim 31, wherein the core and coil are movable within an opening in the magnets.

41. A linear electrical machine comprising:

a coil adapted to carry electrical current;

a core disposed in relation to the coil to provide a path for a magnetic flux linking with the coil, the core having a gap;

first, second and third magnets arranged along a longitudinal axis to interact with a magnetic flux in the core linking with the coil, the first magnet being adjacent the second magnet, and the second magnet being adjacent the third magnet, one of the first, second and third magnets having a magnetic orientation such that a north pole of the magnet is oriented parallel to the longitudinal axis; and

a fourth magnet positioned in the gap of the core and having a magnetic orientation;

wherein at least one of the first, second and third magnets and the core is arranged to move relative to the other in a linear direction parallel to the longitudinal axis, and the magnetic orientation of the fourth magnet is arranged to urge one of the first, second and third magnets to align with the core.

42. The machine of claim 41, wherein none of the magnets included with the movable element have a magnetic orientation such that a north pole of the magnet is oriented in a direction away from the core.

43. The machine of claim 41, wherein each magnet comprises a plurality of separate magnet segments arranged in an annular configuration.

44. The machine of claim 41, wherein the magnets are annular magnets and a soft magnetic material is disposed inside or outside the magnets.

45. The machine of claim 41, wherein the core includes two halves that are assembled together in a clam-shell type arrangement to receive coil inside.

46. The machine of claim 41, wherein the spring magnet urges one of the magnets to align with the spring magnet.

47. The machine of claim 46, wherein the spring magnet urges the second magnet to align with the spring magnet.

48. The machine of claim 41, wherein the magnets include a first annular magnet adjacent a second annular magnet, and a third annular magnet adjacent the second annular magnet, the first and third annular magnets have a north pole parallel to the longitudinal axis, and the second annular magnet has a north pole perpendicular to the longitudinal axis.

49. The machine of claim 48, wherein the second annular magnet has a north pole oriented radially outward, and the first and third annular magnets each have a north pole oriented toward second annular magnet.

50. The machine of claim 49, wherein the core comprises a central opening, and the magnets move inside the central opening.

51. The machine of claim 41, wherein each of the magnets have a length in a direction parallel to the longitudinal axis greater than one-half of a peak displacement of the magnets from a central position along the longitudinal axis.

52. A linear electrical machine comprising:

a coil adapted to carry electrical current;

a core disposed at least partially around the coil that provides a path for a magnetic flux, the core having an annular shape with a central opening and being formed from a powdered, soft magnetic substance; and

a movable element having a longitudinal axis adapted to linearly reciprocate in the central opening along the longitudinal axis, the movable element having magnets arranged along the longitudinal axis.